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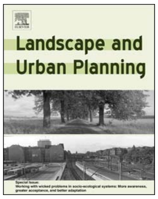

Research Paper

Exurban housing development, onsite wastewater disposal, and groundwater vulnerability within a changing policy context

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ABSTRACT

On-site wastewater treatment systems (OWTS) are designed to collect, filter, and release treated wastewater effluent back into the natural environment. If these decentralized systems are not properly installed or regularly maintained, or are spatially distributed at densities that exceed the landscape's ability to safely treat wastewater effluent, groundwater can become contaminated. We examine in this paper the evolution of state-level policies regulating on-site wastewater management in the State of Wisconsin (USA). We also present a spatiotemporal analysis of on-site wastewater systems installed in a metropolitan county within southeastern Wisconsin. Findings show: 1) advances in OWTS technologies, coupled with regulatory policy changes, have reduced the influence of physiographic constraints on exurban housing development, 2) over 7,000 on-site wastewater systems are unevenly distributed across the county's landscapes, and 3) several OWTS clusters are at high enough densities to threaten groundwater quality, potentially posing public health risks from polluted private well-water. Groundwater contamination risk was assessed, county-wide, by using GIS overlay analysis to compare septic system density (greater than 2.0 systems per acre) with groundwater vulnerability. Our spatial analysis identified several "hot spots" that may warrant groundwater monitoring and OWTS inspections to limit potential health impacts. This method of analysis can help public sector planners design context-sensitive policies to manage unsewered housing development within the rural landscape.

1. Introduction

Population growth and decentralization have transformed many rural landscapes in the United States over the past six decades, especially in areas rich in natural amenities (Brown, Johnson, Loveland, & Theobald, 2005; Gustafson, Hammer, Radeloff, & Potts, 2005; Radeloff, Hammer, & Stewart, 2005). Suburban housing development in the 1950s and 1960s was relatively compact and contiguous to existing urban areas in the U.S., though often planned and constructed with little regard for protecting the natural environment (Rome, 2001). In the 1970s, exurban housing development – residential areas within 50 miles (80 km) of a Metropolitan Statistical Area (MSA) – became popular during the "Rural Rebound" when millions migrated to where natural amenities were abundant and residents could still easily access urban and suburban jobs with their private vehicles (Krannich, Luloff, & Field, 2011; Osgood & Jeffery, 2011). Interstate and intrastate highway networks helped to weaken the "friction of distance" and facilitate housing development in rural areas and smaller municipalities, often within commuting distances of major metropolitan areas (Frey, 2002; Johnson & Cromartie, 2006).

This trend slowed during the economic recession of the 1980s, but exurban growth and migration to nonmetropolitan areas reemerged in the 1990s as the economy improved (Johnson & Cromartie, 2006). Although these outward migrations slowed, again, after the Great Recession of 2007–08, housing development continues beyond the urban fringe, driven in part by the aesthetic and recreational amenities of rural landscapes (Frey, 2012; Gude, Hansen, Rasker, & Maxwell, 2006; Osgood & Jeffery, 2011). By 2010, more than 10.8 million people lived in exurban areas of MSAs with populations of 500,000 or more, comprising as much as 20% of the total metro population and six percent of the U.S. population (Berube, Singer, Wilson, & Frey, 2006). In areas *with* access to municipal sewerage infrastructure, residential wastewater is piped to centralized sewage treatment facilities where impurities are removed before the remaining water is returned to a nearby river, lake, or in some instances, used to recharge deep aquifers. In areas *without* access to municipal sewerage infrastructure, typically each household is served by a private on-site wastewater treatment system (OWTS).

A complex array of local, state, and federal policies influence land

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Table 1
Ozaukee County OWTS Permits, by Type, as of Dec. 31, 2010.

System Type	Policy Period			Totals
	MIN	PRE	PER	
Conventional	3182	443	160	3785
Non-Pressurized	3181	380	135	3696
Pressurized	1	63	25	89
Alternative	97	1435	1362	2894
At Grade	3	80	65	148
Mound	87	1350	1296	2733
Other	7	5	1	13
Holding Tanks	111	812	259	1182
Total	3390	2690	1781	7861

Note: MIN = Minimum Regulations (Pre-1980); PRE = Prescriptive Regulations (1980–2000); PER = Performance Regulations (2000–2010).

use patterns and practices – and landscape change – beyond the urban-rural fringe. This research was motivated by our interest in the complex linkages between state and local land use policies, on-site wastewater system technologies, exurban housing patterns, local hydrogeologic conditions, and environmental risks to public health. Focusing on a metropolitan county in southeastern Wisconsin's karst terrain, we assessed the spatial and temporal distribution of on-site wastewater management systems over three distinct periods of state regulatory policy significance: 1963–1980, 1980–2000, and 2000–2010 (Table 1). We also examined the spatial coincidence of groundwater vulnerability and high densities of on-site wastewater systems. Three questions guided this landscape research: How have changes in state regulatory policy affected the types of on-site wastewater systems installed over the past six decades? How are the three major types of on-site wastewater systems spatially distributed across the county's rural and semi-rural landscapes? Are there any areas where this spatial distribution poses risks to groundwater quality and private drinking wells, potentially threatening human health?

2. Background

2.1. On-site wastewater treatment in the United States

Housing development in the U.S. is influenced by public policies at the local, state, and national levels. Municipal urban service areas provide access to centralized water sources and sewage treatment facilities, for example, and play an important role in growth management at, and beyond, the urban fringe (Hanley & Hopkins, 2007). In rural landscapes not served by these municipal services, on-site wastewater treatment technologies and permissive land use policies can reduce the influence of physiographic conditions on exurban housing patterns (LaGro, 1996, 1998; Rome, 2001). Advances in on-site wastewater treatment technologies have enabled housing construction on sites that were once considered unsuitable for residential development. These site constraints typically include poorly-drained soils and shallow depths to the underlying bedrock or groundwater table (Butler & Payne, 1995).

An in-ground **"conventional"** system sends effluent to a soil absorption field either by gravity-flow (non-pressurized) or by pumping (pressurized). These systems work well in areas with well-drained soils when these systems are designed to serve fewer than 20 people (USEPA, 2002). If these systems are properly sited, installed, and maintained, they can provide trouble-free service for more than twenty years. Only about one-third of the U.S. land area is suited for conventional systems, however. Unsewered development on the remaining land area requires the use of either **holding tanks**, where permitted, or more highly engineered **"alternative"** systems (USEPA, 2002). Holding tanks simply store wastewater for pumping and transport to a municipal sewage treatment facility, and do not disperse effluent into the soil, if maintained properly. Alternative treatment systems incorporate one or more components to pre-treat wastewater before it is released to the leach field (which, depending on native soil conditions, may be constructed as an above-grade mound). These pre-treatment components include aerobic treatment units (ATUs), intermittent sand filters, ultraviolet (UV) lamps, and pumps which require regular inspection and maintenance to sustain reliable performance (USEPA, 2005). To construct above-ground absorption fields, sand is typically transported to those sites.

Rural residences using on-site wastewater systems can introduce nitrates, bacteria, viruses, and other contaminants into local groundwater resources (Bradbury, Rayne, & Krause, 2015; McGinley, Devita, & Nitka, 2015; Shaw, Arntsen, & VanRyswyk, 1993). Rigorous testing of newer OWTS technology reveals that alternative mound systems may not be as reliable, as previously thought, for removing fecal contaminants and other microorganisms from wastewater (Standridge, Olstadt, & Sonzogni, 2001). Moreover, holding tanks made from steel or manufactured concrete can rapidly deteriorate under field conditions, adding yet another potential source of effluent contamination. Failing on-site wastewater systems potentially contaminate surface water and municipal and private wells, threaten other environmental resources, and increase the risks of disease outbreaks (Borchardt et al., 2011; Bradbury et al., 2013; McDowell, Brick, Clifford, Frode-Hutchins, Harvala K. Knudsen, 2005; Scandura & Sobsey, 1997; Schenck et al., 2015; Wilcox, Bradbury, Thomas, & Bahr, 2005; Yates, 1985). Bacterial and chemical contamination of groundwater or surface water can negatively affect human health and environmental quality. Elevated nitrate levels, high bacterial counts, or other water pollutants frequently result in temporary beach closures (Schoen & Ashbolt, 2010). There is also evidence that known groundwater and surface water contamination impact real estate markets and can create financial burdens when dealing with site cleanups and property transfers (Rabinowitz, 1995).

The federal Environmental Protection Agency (EPA), in partnership with state agencies, has the authority to reduce pollution of the nation's groundwater and surface waters (Andreen, 2004; Copeland, 2014). The EPA estimates that, in 2007, 20% (26.1 million) of total U.S. housing units were served by septic systems (USEPA, 2008). Most of these systems consist of a septic tank and a soil infiltration system or drain field. The EPA predicts that malfunctioning or failing systems could be the second greatest threat to groundwater quality in the U.S. and can cost the average home owner thousands of dollars to remedy problems if the systems are not maintained (EPA, 2005). State and local governments can help to protect environmental quality and human health by ensuring that OWTS are properly designed, installed, and managed (USEPA, 2002).

2.2. On-site wastewater treatment policy in the State of Wisconsin

The State of Wisconsin, in the Upper Midwest region of the United States, has a humid temperate climate, relatively subtle topographic relief, and soils of glacial origin covering all but the southwestern portion of the state. Bordered by two of the nation's Great Lakes, Wisconsin's glaciated region is geologically young, with moderately dissected landscapes and poor surface drainage; consequently, many marshes and small lakes are scattered throughout the state (USDA, 1970). About 200,000 OWTS, mostly conventional systems, were installed in Wisconsin prior to 1969 when the state placed few restrictions on on-site wastewater systems (WDOC, 1999). As these systems began to fail and contaminate local water resources, newly implemented statewide restrictions required at least three feet of *in situ* soil (above the bedrock and water table) for new on-site wastewater treatment systems (Jaskula & Hohn, 2002). Thus, in Wisconsin, as in many other states, local environmental conditions became important factors in siting rural housing development (Macrellis & Douglas, 2009). High water tables and wetlands are common constraints in the state's central and northeastern regions; shallow bedrock is a common constraint in